Calculation of load capacity of spur and helical gears —

Part 5:
Strength and quality of materials

Calcul de la capacité de charge des engrenages cylindriques à dentures droite et hélicoïdale —
Partie 5: Résistance et qualité des matériaux
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO’s adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

The committee responsible for this document is ISO/TC 60, Gears, Subcommittee SC 2, Gear capacity calculation.

This third edition cancels and replaces the second edition (ISO 6336-5:2003), which has been technically revised to reflect current practices throughout the industry.

A list of all parts in the ISO 6336 series can be found on the ISO website.
Introduction

This document, together with ISO 6336-1, ISO 6336-2, ISO 6336-3 and ISO 6336-6, provides the principles for a coherent system of procedures for the calculation of the load capacity of cylindrical involute gears with external or internal teeth. ISO 6336 is designed to facilitate the application of future knowledge and developments, as well as the exchange of information gained from experience.

Allowable stress numbers, as covered by this document, may vary widely. Such variation is attributable to defects and variations of chemical composition (charge), structure, the type and extent of hot working (e.g. bar stock, forging, reduction ratio), heat treatment, residual stress levels, etc.

Tables summarize the most important influencing variables and the requirements for the different materials and quality grades. The effects of these influences on surface durability and tooth bending strength are illustrated by graphs.

This document covers the most widely used ferrous gear materials and related heat treatment processes. Recommendations on the choice of specific materials, heat treatment processes or manufacturing processes are not included. Furthermore, no comments are made concerning the suitability or otherwise of any materials for specific manufacturing or heat treatment processes.
Calculation of load capacity of spur and helical gears —

Part 5:
Strength and quality of materials

1 Scope

This document describes contact and tooth-root stresses and gives numerical values for both limit stress numbers. It specifies requirements for material quality and heat treatment and comments on their influences on both limit stress numbers.

Values in accordance with this document are suitable for use with the calculation procedures provided in ISO 6336-2, ISO 6336-3 and ISO 6336-6 and in the application standards for industrial, high-speed and marine gears. They are applicable to the calculation procedures given in ISO 10300 for rating the load capacity of bevel gears. This document is applicable to all gearing, basic rack profiles, profile dimensions, design, etc., covered by those standards. The results are in good agreement with other methods for the range indicated in the scope of ISO 6336-1 and ISO 10300-1.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 53, Cylindrical gears for general and heavy engineering — Standard basic rack tooth profile

ISO 642, Steel — Hardenability test by end quenching (Jominy test)

ISO 643:2012, Steels — Micrographic determination of the apparent grain size

ISO 683-1, Heat-treatable steels, alloy steels and free-cutting steels — Part 1: Non-alloy steels for quenching and tempering

ISO 683-2, Heat-treatable steels, alloy steels and free-cutting steels — Part 2: Alloy steels for quenching and tempering

ISO 683-3, Heat-treatable steels, alloy steels and free-cutting steels — Part 3: Case-hardening steels


ISO 683-5, Heat-treatable steels, alloy steels and free-cutting steels — Part 5: Nitriding steels

ISO 1328-1, Cylindrical gears — ISO system of flank tolerance classification — Part 1: Definitions and allowable values of deviations relevant to flanks of gear teeth

ISO 2639, Steels — Determination and verification of the depth of carburized and hardened cases

ISO 3754, Steel — Determination of effective depth of hardening after flame or induction hardening

ISO 4948-2, Steels — Classification — Part 2: Classification of unalloyed and alloy steels according to main quality classes and main property or application characteristics

ISO 4967, Steel — Determination of content of non-metallic inclusions — Micrographic method using standard diagrams
3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in ISO 1122-1 and the symbols and units given in ISO 6336-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:
— ISO Online browsing platform: available at http://www.iso.org/obp

4 Methods for the determination of allowable stress numbers

4.1 General

Allowable stress numbers should be determined for each material and material condition, preferably by means of gear running tests. Test conditions and component dimensions should equate, as nearly as is practicable, to the operating conditions and dimensions of the gears to be rated.

When evaluating test results or data derived from field service, it is always necessary to ascertain whether or not specific influences on permissible stresses are already included with the evaluated data, e.g. in the case of surface durability, the effects of lubricants, surface roughness and gear geometry; in

1) American Society for Testing and Materials
the case of tooth bending strength, the fillet radius, surface roughness and gear geometry. If a specific influence is included in the permissible stress derived from tests or from field service data, then the relevant influence factor should be set equal to 1,0 in the calculation procedure of ISO 6336-2 and ISO 6336-3.

4.2 Method A

The allowable stress numbers for contact and bending are derived from endurance tests of gears having dimensions closely similar to those of the gears to be rated, under test conditions which are closely similar to the intended operating conditions.

4.3 Method B

The allowable stress numbers for contact and bending were derived from endurance tests of reference test gears under reference test conditions. Tooth-root allowable stress numbers were also derived from pulsator tests. Practical experience should be taken into account. The standard allowable stress numbers specified in 5.2 and 5.3 are based on such tests and experience.

Three different classes, ME, MQ and ML, are given for the allowable stress numbers. The appropriate choice of class will depend, as described in Clause 6, on the type of production and quality control exercised.

4.4 Method $B_r$

Contact stress numbers derived from rolling contact fatigue testing have to be used with caution since they tend to overestimate allowable contact stress numbers for gear teeth.

4.5 Method $B_k$

Allowable stress numbers for bending are derived from the results of testing notched test pieces. Preferably, the ratio of the test piece notch radius to thickness should be similar to that of the fillet radius to the tooth-root chord in the critical section and the surface condition should be similar to that of the tooth root. When evaluating test data, it should be understood that test pieces are usually subjected to repeating bending stress, whereas in the case of a gear tooth, the fillets of the teeth are subjected to combined bending, shear and compressive stresses. Data on the various materials can be obtained from in-house testing, experience or from literature.

4.6 Method $B_p$

Allowable stress numbers for bending are derived from the results of testing un-notched test pieces. See 4.5 for comments on evaluation of test results. In order to take into account the effect of notch sensitivity, it is necessary that actual notch form and notch factors be included in calculations; thus, their results will be influenced by the extreme unreliability of these factors. Data on the various materials can be obtained from known test facilities or from literature.

5 Standard allowable stress numbers — Method B

5.1 Application

The allowable stress numbers shall be derived from Figures 1 to 16 or calculated by Formula 2 and Table 1.

The allowable stress numbers shown in Figures 1 to 16 are based on the assumption that material composition, heat treatment and inspection methods are appropriately chosen for the size of the gear.

If test values for specific materials are available, they can be used in replacement of the values in Figures 1 to 16.
The data furnished in this document are well substantiated by tests and practical experience.

The values are chosen for 1 % probability of damage. Statistical analysis enables adjustment of these values in order to correspond to other probabilities of damage but such adjustments need to be considered very carefully and may require additional specific tests or detailed documentation of the source of the information used to derive the confidence level of the failure probabilities.

When other probabilities of damage (reliability) are desired, the values of $\sigma_{H\lim}$, $\sigma_{F\lim}$ and $\sigma_{FE}$ are adjusted by an appropriate “reliability factor.” When this adjustment is made, a subscript shall be added to indicate the relevant percentage (e.g. $\sigma_{H\lim10}$ for 10 % probability of damage). For statistical analysis of fatigue testing results, see also Reference [6].

The allowable stress numbers indicated in Figures 9 and 10 were derived for effective case depths of about 0,15$m_n$ to 0,2$m_n$ on finish-machined gears.

The extent to which the level of surface hardness influences the strength of contour-hardened, nitrided, carbo-nitrided and nitro-carburized gears cannot be reliably specified. Other surface-related factors of the material and heat treatment have a much more pronounced influence.

In some cases, the full hardness range is not covered. The ranges covered are indicated by the length of the lines in Figures 1 to 16.

For surface hardened steels (Figures 9 to 16), the HV scale was chosen as the reference axis. The HRC scale is included for comparison. To define the relationship between Vickers and Rockwell hardness numbers conversion tables, see ISO 18265.

5.2 Allowable stress number (contact), $\sigma_{H\lim}$

The allowable stress number, $\sigma_{H\lim}$, is derived from a contact pressure that may be sustained for a specified number of cycles without the occurrence of progressive pitting. For the beginning of the long-life area refer to the life factor $Z_{NT}$ for the different materials in ISO 6336-2 (for example case carburized, through hardened, and induction-hardened material $5 \times 10^{7}$, stress cycles are considered to be the beginning for the long life area).

Values of $\sigma_{H\lim}$ indicated in Figures 1, 3, 5, 7, 9, 11, 13 and 15 are appropriate for the reference operating conditions and dimensions of the reference test gears, as follows:

<table>
<thead>
<tr>
<th>Condition</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centre distance</td>
<td>$a = 100$ mm</td>
</tr>
<tr>
<td>Helix angle</td>
<td>$\beta = 0$ ($Z_{\beta} = 1$)</td>
</tr>
<tr>
<td>Module</td>
<td>$m = 3$ mm to 5 mm ($Z_{m} = 1$)</td>
</tr>
<tr>
<td>Mean peak-to-valley roughness of the tooth flanks</td>
<td>$R_z = 3 \mu m$ ($Z_{R} = 1$)</td>
</tr>
<tr>
<td>Tangential velocity</td>
<td>$v = 10$ m/s ($Z_{v} = 1$)</td>
</tr>
<tr>
<td>Lubricant viscosity</td>
<td>$\nu_{50} = 100$ mm$^2$/s ($Z_{L} = 1$)</td>
</tr>
<tr>
<td>Mating gears of the same material</td>
<td>($Z_{W} = 1$)</td>
</tr>
<tr>
<td>Gearing accuracy grades</td>
<td>4 to 6 according to ISO 1328-1</td>
</tr>
<tr>
<td>Face width</td>
<td>$b = 10$ mm to 20 mm</td>
</tr>
<tr>
<td>Load influence factors</td>
<td>$K_{A} = K_{v} = K_{H\beta} = K_{H\alpha} = 1$</td>
</tr>
</tbody>
</table>

2) Data obtained under different conditions of testing were adjusted to be consistent with reference conditions. It is important to note $\sigma_{H\lim}$ is not the contact pressure under continuous load, but rather the upper limit of the contact pressure derived in accordance with ISO 6336-2, which can be sustained without progressive pitting damage, for a specified number of load cycles.
Test gears were deemed to have failed by pitting when the following conditions were met: when 2 % of the total working flank area of through hardened gears, or when 0,5 % of the total working flank area of surface hardened gears, or 4 % of the working flank area of a single tooth, is damaged by pitting. The percentages refer to test evaluations; they are not intended as limits for product gears.

5.3 Bending stress number values for $\sigma_{F \text{ lim}}$ and $\sigma_{FE}$

5.3.1 Nominal stress numbers (bending), $\sigma_{F \text{ lim}}$

The nominal stress number (bending), $\sigma_{F \text{ lim}}$, was determined by testing reference test gears (see ISO 6336-3). It is the bending stress limit value relevant to the influences of the material, the heat treatment and the surface roughness of the test gear root fillets.

5.3.2 Allowable stress number (bending), $\sigma_{FE}$

The allowable stress number for bending, $\sigma_{FE}$ (for the definition of $\sigma_{FE}$, see ISO 6336-3), is the basic bending strength of the un-notched test piece, under the assumption that the material condition (including heat treatment) is fully elastic:

$$\sigma_{FE} = \sigma_{F \text{ lim}} \cdot Y_{ST}$$

(1)

For the reference test gear, the stress correction factor $Y_{ST} = 2,0$. For all materials covered in this document, $3 \times 10^6$ stress cycles are considered to be the beginning of the long-life strength range (see life factor $Y_{\text{NT}}$ in ISO 6336-3).

Values of $\sigma_{F \text{ lim}}$ and $\sigma_{FE}$ indicated in Figures 2, 4, 6, 8, 10, 12, 14 and 16 are appropriate for the reference operating conditions and dimensions of the reference test gears, as shown below (see 5.2):

— Helix angle $\beta = 0$ ($Y_{\beta} = 1$)
— Module $m = 3 \text{ mm to } 5 \text{ mm}$ ($Y_{X} = 1$)
— Stress correction factor $Y_{ST} = 2,0$
— Notch parameter $q_{ST} = 2,5$ ($Y_{\delta_{\text{rel-T}}} = 1$)
— Mean peak-to-valley roughness of the tooth fillets $R_{z} = 10 \mu m$ ($Y_{R_{\text{rel-T}}} = 1$)
— Gearing accuracy grades 4 to 7 according to ISO 1328-1
— Basic rack according to ISO 53
— Face width $b = 10 \text{ mm to } 50 \text{ mm}$
— Load factors $K_{A} = K_{F} = K_{F\beta} = K_{F\alpha} = 1$

5.3.3 Reversed bending

The allowable stress numbers indicated in Figures 2, 4, 6, 8, 10, 12, 14 and 16 are appropriate for repeated, unidirectional, tooth loading. When reversals of full load occur, a reduced value of $\sigma_{FE}$ is required. In the most severe case (e.g., an idler gear where full load reversal occurs each load cycle), the values $\sigma_{F \text{ lim}}$ and $\sigma_{FE}$ should be reduced to 0,7 times the unidirectional value. If the number of load reversals is less frequent than this, a different factor, depending on the number of reversals expected during the gear lifetime, can be chosen. For guidance on this, see ISO 6336-3:2006, Annex B.